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TECHNICAL MANUAL FOR MEASUREMENT OF FUGITIVE EMISSIONS

UPWIND/DOWNWIND SAMPLING METHOD FOR INDUSTRIAL EMISSIONS

RESEARCH CORPORATION OF NEW ENGLAND

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16. ABSTRACT The manual provides a guide for the implementation of the Upwind/Downwind Sampling Strategy in the measurement of fugitive emissions. Criteria for the selection of the most applicable measurement method and discussions of general information gathering and planning activities are presented. Upwind/downwind sampling strategies and equipment are described. The design of the sampling system, sampling techniques, and data reduction procedures are discussed. Manpower requirements and time estimates for typical applications of the method are presented for programs designed for overall and specific emissions measurements. The application of the outlined procedures to the measurement of fugitive emissions from a Portland cement manufacturing plant is presented as an appendix.

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1.0 OBJECTIVE

The objective of this procedures document is to present a guide for the utilization of the Upwind-Downwind Sampling Strategy in the measurement of fugitive emissions. Criteria for the selection of the most applicable measurement method and discussions of general information gathering and planning activities are presented. Upwind-downwind sampling strategies and equipment are described and sampling system design, sampling techniques, and data reduction are discussed.

Manpower requirements and time estimates for typical applications of the method are presented for programs designed for overall and specific emissions measurements.

The application of the outlined procedures to the measurement of fugitive emissions from a Portland cement manufacturing plant is presented as an appendix.

2.0 INTRODUCTION

Pollutants emitted into the ambient air from an industrial plant or other site generally fall into one of two types. The first type is released into the air through stacks or similar devices designed to direct and control the flow of the emissions. These emissions may be readily measured by universally-recognized standard stack sampling techniques. The second type is released into the air without control of flow or direction. These fugitive emissions usually cannot be measured using existing standard techniques.

The development of reliable, generally applicable measurement procedures is a necessary prerequisite to the development of strategies for the control of fugitive emissions. This document describes some procedures for the measurement of fugitive emissions using the upwind-downwind measurement method described in Section 2.1.3 below.

2.1 Categories of Fugitive Emissions

Fugitive emissions emanate from such a wide variety of circumstances that it is not particularly meaningful to attempt to categorize them either in terms of the processes or mechanisms that generate them, or the geometry of the emission points. A more useful approach is to categorize fugitive emissions in terms of the methods for their measurement. Three basic methods exist--quasi-stack sampling, roof monitor sampling, and upwind-downwind sampling. Each is described in general terms below.

2.1.1 Quasi-Stack Sampling Method

In this method, the fugitive emissions are captured in a temporarily installed hood or enclosure and vented to an exhaust duct or stack of

regular cross-sectional area. Emissions are then measured in the exhaust duct using standard stack sampling or similar well recognized methods. This approach is necessarily restricted to those sources of emissions that are isolable and physically arranged so as to permit the installation of a temporary hood or enclosure that will not interfere with plant operations or alter the character of the process or the emissions.

2.1.2 Roof Monitor Sampling Method

This method is used to measure the fugitive emissions entering the ambient air from building or other enclosure openings such as roof monitors, doors and windows. The method is especially applicable to situations in which enclosed sources are too numerous or physically configured to preclude the application of the quasi-stack method to each source. Sampling is, in general, limited to a mixture of all uncontrolled emission sources within the enclosure and requires the ability to make low velocity exhaust air measurements and mass balances of small quantities of materials entering and leaving the enclosure through the openings.

2.1.3 Upwind-Downwind Sampling Method

This method is utilized to measure the fugitive emissions from sources typically covering large areas that cannot be temporarily hooded and are not enclosed in a structure allowing the use of the roof monitor method. Such sources include material handling and storage operations, waste dumps, and industrial processes in which the emissions are spread over large areas. These features are embodied in the typical

industrial sources and their emitted pollutants listed in Table 2-1.

The upwind-downwind method quantifies the emissions from such sources as the difference between the pollutant concentrations measured in the ambient air approaching (upwind) and leaving (downwind) the source site. It may also be utilized in combination with mathematical models and tracer tests to define the contributions to total measured emissions of specific sources among a group of sources.

2.2 Sampling Method Selection

The initial step in the measurement of fugitive emissions at an industrial site is the selection of the most appropriate sampling method to be employed. Although it is impossible to enumerate all the combinations of influencing factors that might be encountered in a specific situation, careful consideration of the following general criteria should result in the selection of the most effective of the three sampling methods described above.

2.2.1 Selection Criteria

The selection criteria listed below are grouped into three general classifications common to all fugitive emissions measurement methods. The criteria are intended to provide only representative examples and should not be considered a complete listing of influencing factors.

2.2.1.1 Site Criteria

Source Isolability. Can the emissions be measured separately from emissions from other sources? Can the source be enclosed?

Source Location. Is the source indoors or out? Does location

TABLE 2-1

UPWIND-DOWNWIND SAMPLING METHOD
APPLICATION TO TYPICAL INDUSTRIAL FUGITIVE EMISSION SOURCES

Industry	Source	Particulate Emissions	Gas & Vapor Emissions
Coke Making	Coal Handling	Coal Dust	-
	Coal Storage	Coal Dust	-
	Charging Ovens	Coal Dust, Tars	HC, CO, NO_x, H_2S, SO_2, NH_3, Pyridine
	Coking, Door & Oven Leaks	Coke Dust, Tars	HC, CO, NO_x, H_2S, NH_3, CS_2, Phenol
	Coke Pushing	Coke Dust, Tars	HC, CO, H_2S, NH_3, HCN, Phenol
	Quenching (Controlled but some leaks)	Coke Dust, Tars	HC, CO, H_2S, NH_3, HCN, SO_2, Phenol
	Coke Handling	Coke Dust	-
	Coke Storage		
Primary Aluminum	Bauxite Handling & Storage	Ore Dust	-
	Alumina Calcining & Preparation	Alumina Dust	-
	Alumina Storage	Alumina Dust	-
Primary Copper	Mining	Dust	-
	Hauling	Dust	-
	Tailings Pond	Dust	-
	Slag Dump	-	SO_2
Sand & Gravel	Quarrying	Dust	
	Truck Hauling	Dust	
	Delivery & Storage	Dust	
	Rock Transfer	Dust	
	Crushing & Screening	Dust	
	Drying (Leakage)	Dust	
	Product Storage	Dust	
	Product Loading	Dust	
	Product Delivery	Dust	
Electric Furnace Steel	Scrap & Sinter Delivery	Iron Dust Steel Dust	-
	Lime & Silica Delivery	Dust	-
	Pollution Control Equipment - Dust Transfer & Storage	Fume Dust	
	Storage Ponds for Slagging Waste Water	-	H_2S, SO_2
Iron & Steel Foundries	Coke, Silica Sinter Delivery & Storage	Dust	-
	Pollution Control Equipment Transfer & Storage	Dust	-
Coal	Mining	Coal Dust	-
	Hauling	Coal Dust	-
	Storage & Transfer	Coal Dust	-
	Screening & Crushing	Coal Dust	
	Transfer	Coal Dust	
	Drying	Coal Dust	Hydrocarbons,
	Storage Piles	Coal Dust	CO
	Waste Transfer	Dust	
Asphalt	Gravel Delivery	Dust	
	Asphalt Storage	Tars	Hydrocarbons, Odors
	Storage Piles	Dust	
	Asphalt Batching	Dust, Tars	Hydrocarbons, Odor
	Drier & Blower	Dust, Tars	Hydrocarbons, Odor
	Reactor Discharge	Dust, Tars	Hydrocarbons, Odor
	Reactor Charge	Dust, Tars	Hydrocarbons, Odor
	Product Transfer	Dust, Tars	Hydrocarbons, Odor
Coal Gasification	Coal Delivery & Storage	Coal Dust	
	Coal Transfer	Coal Dust	
	Waste Transfer	Dust	Hydrocarbons, H_2S, NH_3, SO_2 Phenol
	Scrubber Solids	Dust	Hydrocarbons
	Settling Pond		H_2S, SO_2, NH_3 Phenol, Hydrocarbons
Petroleum Refining	Crude Transfer	-	Hydrocarbons, RSH, H_2S
	Crude Storage		Hydrocarbons, RSH, H_2S
	Distilate Storage		Hydrocarbons
	Distilate Transfer		Hydrocarbons
	Gasoline Storage & Transfer		Hydrocarbons
	Leakage in Drains & Sewers		Hydrocarbons, H_2S, HF, Phenols
	Waste Water Storage & Transfer	Dust	H_2S, SO_2, NH_3, Phenols, HF, Hydrocarbons
	Process Leaks	Tars	H_2S, SO_2, NH_3, Phenols, HF, Hydrobarbons
	Gasoline Terminal Loading		Hydrocarbons
Phosphate Fertilizer	Mining	Dust	
	Storage Piles	Dust	
	Rock Transfer (Truck, Conveyer)	Dust	
	Settling Pond	Fluorides	SO_2, Fluorides
	Gypsum File	Dust	SO_2
	Product Storage	Dust	Fluorides
	Product Delivery	Dust	Fluorides

permit access of measuring equipment?

Meteorological Conditions. What are the conditions representative of typical and critical situations? Will precipitation interfere with measurements? Will rain or snow on ground effect dust levels?

2.2.1.2 Process Criteria

Number and Size of Sources. Are emissions from a single, well defined location or many scattered locations? Is source small enough to hood?

Homogeneity of Emissions. Are emissions the same type everywhere at the site? Are reactive effects between different emissions involved?

Continuity of Process. Will emissions be produced long enough to obtain meaningful samples?

Effects of Measurements. Are special procedures required to prevent the making of measurements from altering the process or emissions or interfering with production? Are such procedures feasible?

2.2.1.3 Pollutant Criteria

Nature of Emissions. Are measurements of particles, gases, liquids required? Are emissions hazardous?

Emission Generation Rate. Are enough emissions produced to provide measurable samples in reasonable sampling time?

Emission Dilution. Will transport air reduce emission concentration below measurable levels?

2.2.2 Application of Criteria

The application of the selection criteria listed in Section 2.2.1 to each of the fugitive emissions measurement methods defined in Section 2.1 is described in general terms in this section.

2.2.2.1 Quasi-Stack Method

Effective use of the quasi-stack method requires that the source of emissions be isolable and that an enclosure can be installed capable of capturing emissions without interference with plant operations. The location of the source alone is not normally a factor. Meteorological conditions usually need be considered only if they directly affect the sampling.

The quasi-stack method is usually restricted to a single source and must be limited to two or three small sources that can be effectively enclosed to duct their total emissions to a single sampling point. Cyclic processes should provide measurable pollutant quantities during a single cycle to avoid sample dilution. The possible effects of the measurement on the process or emissions is of special significance in this method. In many cases, enclosing a portion of a process in order to capture its emissions can alter that portion of the process by changing its temperature profile or affecting flow rates. Emissions may be similarly altered by reaction with components of the ambient air drawn into the sampling ducts. While these effects are not necessarily limiting in the selection of the method, they must be considered in designing the test program and could influence the method selection by increasing complexity and costs.

The quasi-stack method is useful for virtually all types of emissions. It will provide measurable samples in generally short sampling times since it captures essentially all of the emissions. Dilution of the pollutants of concern is of little consequence since it can usually be controlled in the design of the sampling system.

2.2.2.2 Roof Monitor Method

Practical utilization of the roof monitor method demands that the source of emissions be enclosed in a structure with a limited number of openings to the atmosphere. Measurements may usually be made only of the total of all emissions sources within the structure. Meteorological conditions normally need not be considered in selecting this method unless they have a direct effect on the flow of emissions through the enclosure opening.

The number of sources and the mixture of emissions is relatively unimportant since the measurements usually include only the total emissions. The processes involved may be discontinuous as long as a representative combination of the typical or critical groupings may be included in a sampling. Measurements will normally have no effect on the processes or emissions.

The roof monitor method, usually dependent on or at least influenced by gravity in the transmission of emissions, may not be useful for the measurement of larger particulates which may settle within the enclosure being sampled. Emission generation rates must be high enough to provide pollutant concentrations of measurable magnitude after dilution in the enclosed volume of the structure.

2.2.2.3 Upwind-Downwind Method

The upwind-downwind method, generally utilized where neither of the other methods may be successfully employed, is not influenced by the number or location of the emission sources except as they influence

the locating of sampling devices. In most cases, only the total contribution to the ambient atmosphere of all sources within a sampling area may be measured. The method is strongly influenced by meteorological conditions, requiring a wind consistent in direction and velocity throughout the sampling period as well as conditions of temperature, humidity and ground moisture representative of normal ambient conditions.

The emissions measured by the upwind-downwind method may be the total contribution from a single source or from a mixture of many sources in a large area. Continuity of the emissions is generally of secondary importance since the magnitude of the ambient air volume into which the emissions are dispersed is large enough to provide a degree of smoothing to cyclic emissions. The measurements have no effect on the emissions or processes involved.

Most airborne pollutants can be measured by the upwind-downwind method. Generation rates must be high enough to provide measurable concentrations at the sampling locations after dilution with the ambient air. Settling rates of the larger particulates require that the sampling system be carefully designed to ensure that representative particulate samples are collected.

2.3 Sampling Strategies

Fugitive emissions measurements may, in general, be separated into two classes or levels depending upon the degree of accuracy desired. Survey measurement systems are designed to screen emissions and provide gross measurements of a number of process influents and effluents at a

relatively low level of effort in time and cost. Detailed systems are designed to isolate, identify, and quantify individual contaminant constituents with increased accuracy and higher investments in time and cost.

2.3.1 Survey Measurement Systems

Survey measurement systems employ recognized standard or state-of-the-art measurement techniques to screen the total emissions from a site or source and determine whether any of the emission constituents should be considered for more detailed investigation. They generally utilize the simplest available arrangement of instrumentation and procedures in a relatively brief sampling program, usually without provisions for sample replication, to provide order-of-magnitude type data, embodying a factor of two to five in accuracy range with respect to actual emissions.

2.3.2 Detailed Measurement Systems

Detailed measurement systems are used in instances where survey measurements or equivalent data indicate that a specific emission constituent may be present in a concentration worthy of concern. Detailed systems provides more precise identification and quantification of specific constituents by utilizing the latest state-of-the-art measurement instrumentation and procedures in carefully designed sampling programs. These systems are also utilized to provide emission data over a range of process operating conditions or ambient meteorological influences. Basic accuracy of detailed measurements is in the order of $\pm$ 10 to $\pm$ 50

percent of actual emissions. Detailed measurement system costs are generally in the order of three to five times the cost of a survey system at a given site.

3.0 TEST PROGRAM PROCEDURES

This section describes the procedures required to successfully complete a testing program utilizing the upwind-downwind sampling method described in Section 2.1. It details the information required to plan the program, describes the organization of the test plan, specifies the types of sampling equipment to be used, establishes criteria for the sampling system design, and outlines basic data reduction methods.

3.1 Pretest Survey

After the measurement method to be utilized in documenting the fugitive emissions at a particular site has been established using the criteria of Section 2.2, a pretest survey of the site should be conducted by the program planners. The pretest survey should result in an informal, internal report containing all the information necessary for the preparation of a test plan and the design of the sampling system by the testing organization.

This section provides guidelines for conducting a pretest survey and preparing a pretest survey report.

3.1.1 Information to be Obtained

In order to design a system effectively and plan for the on-site sampling of fugitive emissions, a good general knowledge is required of the plant layout, process chemistry and flow, surrounding environment, and prevailing meteorological conditions. Particular characteristics of the site relative to the needs of the owner, the products involved, the space and manpower skills available, emission control equipment

installed, and the safety and health procedures observed, will also influence the sampling system design and plan. Work flow patterns and schedules that may result in periodic changes in the nature or quantity of emissions or that indicate periods for the most effective and least disruptive sampling must also be considered. Most of this information can only be obtained by a survey at the site. Table 3-1 outlines some of the specific information to be obtained. Additional information will be suggested by considerations of the particular on-site situation.

3.1.2 Report Organization

The informal, internal pretest survey report must contain all the pertinent information gathered during and prior to the site study. A summary of all communications relative to the test program should be included in the report along with detailed descriptions of the plant layout, process, and operations as outlined in Table 3-1. The report should also incorporate drawings, diagrams, maps, photographs, meteorological records, and literature references that will be helpful in planning the test program.

3.2 Test Plan

3.2.1 Purpose of a Test Plan

Measurement programs are very demanding in terms of the scheduling and completion of many preparatory tasks, observations at sometimes widely separated locations, instrument checks to verify measurement validity, etc. It is therefore essential that all of the experiment design and planning be done prior to the start of the measurement pro-

TABLE 3-1

PRE-TEST SURVEY INFORMATION TO BE OBTAINED
FOR APPLICATION OF FUGITIVE EMISSION SAMPLING METHODS

Plant Layout	Drawings: Building Layout and Plan View of Potential Study Areas Building Side Elevations to Identify Obstructions and Structure Available to Support Test Setup Work Flow Diagrams Locations of Suitable Sampling Sites Physical Layout Measurements to Supplement Drawings Work Space Required at Potential Sampling Sites
Process	Process Flow Diagram with Fugitive Emission Points Identified General Description of Process Chemistry General Description of Process Operations Including Initial Estimate of Fugitive Emissions Drawings of Equipment or Segments of Processes Where Fugitive Emissions are to be Measured Photographs (if permitted) of Process Area Where Fugitive Emissions are to be Measured Names, Extensions, Locations of Process Foremen and Supervisors Where Tests are to be Conducted
Operations	Location of Available Services (Power Outlets, Maintenance and Plant Engineering Personnel, Laboratories, etc.) Local Vendors Who Can Fabricate and Supply Test System Components Shift Schedules Location of Operations Records (combine with process operation information) Health and Safety Considerations
Other	Access routes to the areas Where Test Equipment/Instrumentation Will Be Located Names, Extensions, Locations of Plant Security and Safety Supervisors

gram in the form of a detailed test plan. The preparation of such a plan enables the investigator to "pre-think" effectively and cross-check all of the details of the design and operation of a measurement program prior to the commitment of manpower and resources. The plan then also serves as the guide for the actual performance of the work. The test plan provides a formal specification of the equipment and procedures required to satisfy the objectives of the measurement program. It is based on the information collected in the informal pretest survey report and describes the most effective sampling equipment, procedures, and timetables consistent with the program objectives and site characteristics.

3.2.2 Test Plan Organization

The test plan should contain specific information in each of the topical areas indicated below:

Background

The introductory paragraph containing the pertinent information leading to the need to conduct the measurement program and a short description of the information required to answer that need.

Objective

A concise statement of the problem addressed by the test program and a brief description of the program's planned method for its solution.

Approach

A description of the measurement scheme and data reduction methodology employed in the program with a discussion of how each will answer the needs identified in the background statement.

Instrumentation/Equipment/Facilities

A description of the instrumentation arrays to be used to collect the samples and meteorological data identified in the approach description. The number and frequency of samples to be taken and the sampling array resolution should be described.

A detailed description of the equipment to be employed and its purpose.

A description of the facilities required to operate the measurement program, including work space, electrical power, support from plant personnel, special construction, etc.

Schedule

A detailed chronology of a typical set of measurements or a test, and the overall schedule of events from the planning stage through the completion of the test program report.

Limitations

A definition of the conditions under which the measurement project is to be conducted. If, for example, successful tests can be conducted only during occurrences of certain wind directions, those favorable limits should be stated.

Analysis Method

A description of the methods which will be used to analyze the samples collected and the resultant data, e.g., statistical or case analysis, and critical aspects of that method.

Report Requirements

A draft outline of the report on the analysis of the data to be collected along with definitions indicating the purpose of the report and the audience for which it is intended.

Quality Assurance

The test plan should address the development of a quality assurance program as outlined in Section 3.7. This QA program should be an integral part of the measurement program and be incorporated as a portion of the test plan either directly or by reference.

Responsibilities

A list of persons who are responsible for each phase of the measurement program, as defined in the schedule, both for the testing organization and for the plant site.

3.3 Upwind-Downwind Sampling Strategies

The upwind-downwind sampling method, as described in Section 2.1.3, is used to quantify the emissions from a source to the ambient atmosphere by measuring pollutant levels in the atmosphere. Upwind measurements are made within the ambient air approaching the site of the source, using sampling equipment suitable for the specific emissions to be measured, to determine the baseline concentration of pollutants in the air. Downwind measurements are made of the air within the cloud of pollutants emitted by the source, using sampling equipment similar to that used for the upwind measurements, to determine the total of the ambient air and the source's contribution to the concentration of pollutants. The pollutants contributed by the source to the cloud at the sampling locations are determined as the difference between the measured upwind and downwind concentrations. Measurement of the wind speed and direction at the site are combined with the pollutant concentrations at the sampling locations in diffusion equations to back-calculate the source strength of the emissions. Section 3.4 and 3.5 describe the equipment used for sampling, the criteria for sampling system design, sampling techniques, and data reduction procedures for respectively, survey and detailed upwind-downwind sampling programs.

3.4 Survey Upwind-Downwind Measurement System

A survey measurement system, as defined in Section 2.3, is designed to provide gross measurements of emissions to determine whether any constituents should be considered for more detailed investigation. A survey upwind-downwind measurement system in its simplest form utilizes

a single upwind sampler for the determination of the concentration of the pollutants of concern in the ambient air approaching the source of the emissions and two or three identical downwind samplers for the determination of the pollutant concentration and distribution in the ambient air leaving the source. These data, combined with measurements of the ambient air wind speed and direction, are used to calculate the emission rate of the source.

3.4.1 Sampling Equipment

Pollutants that may be measured by the upwind-downwind technique are limited to those that can be airborne for significant distances, i.e., particulates and gases. The gross measurement requirements for survey sampling of particulates are best satisfied by high volume filter devices to provide data on the average emission rate, particle size distribution, and particle composition. Particle charge transfer or piezoelectric mass monitoring devices may be utilized for continuous or semi-continuous sampling of intermittent emission sources where peak levels must be defined.

Gaseous emissions in survey programs are usually grab-sampled for laboratory analysis using any of a wide variety of evacuated sampling vessels or chemical bubblers. Continuous or semi-continuous sampling of specific gases may be accomplished using such devices as continuous monitor flame ionization detectors (for hydrocarbons) and automated flame photometric devices (for sulfur dioxide).

3.4.2 Sampling System Design

The number and location of the devices used to collect samples is extremely important to the successful completion of a survey upwind-downwind sampling program, especially since the program is designed for minimum cost and provides for no replication of samples. The design of the sampling system is influenced by such factors as source complexity and size, site location and topography, and prevailing meteorological conditions which govern the distribution of the pollutant cloud in the ambient atmosphere. Most situations will in general fit into some combination of the following parameters:

Source - Sources may be either homogeneous, emitting a single type or mixture of pollutants from each and every emission location, or heterogeneous, emitting different types or mixtures of pollutants from different locations. The resultant cloud of pollutants will, for a homogeneous source, be homogeneous. The pollutant cloud for a heterogeneous source may be either heterogeneous or, as a result of mixing by suitably directed or turbulent ambient air flow, homogeneous. The physical size of a source will determine the extent of the pollutant cloud and may influence its homogeneity, the proximity of different emissions to each other largely influencing the degree of mixing in the cloud for a given downwind distance.

Site - Sites in general may be open on level terrain with free access of ambient air from all sides, partially obstructed by hills or buildings that interfere with or influence the ambient air flow either up- or downwind, or located in a valley between hills or large buildings that influence the air flow both up- and downwind. Each type of topography will influence the extent and homogeneity of the pollutant cloud depending on the direction of the wind flow relative to the obstructions.

Meteorology - The direction of the prevailing wind determines the basic location of upwind and downwind samplers. It will influence the pollutant cloud in every instance except that of a homogeneous cloud at an open level site. In other instances, the wind may be directed generally across or parallel to obstructing hills or valleys which may result in channeling, lofting, or swirling of the air flow across the site that will distort the pollutant cloud.

The homogeneity of the ambient air approaching the measurement site, while not in the strict sense a meteorological condition,

may affect the composition and distribution of different pollutants within the pollutant cloud. Contributions from sources upwind of the site may result in variations in the pollutant concentrations in the ambient air passing over the site and thus in the pollutant cloud as well.

Wind speed, which can affect the cloud's size and distribution, need not be considered as a governing design factor since it is to some degree controllable by scheduling to avoid periods of either excessive wind velocity or calm conditions. Wind speeds within normal limits are taken into consideration in data reduction calculations.

Table 3-2 presents a matrix of 20 possible combinations of these parameters (cloud homogeneity, site topography, wind direction and ambient air homogeneity). The simplest combination, that of a homogeneous cloud in an open level site with homogeneous ambient air, would typically require a single upwind sampler and two downwind samplers located within the cloud. The complexity of the sampler system design is, in general, increased by changes in the parameters as follows:

Cloud Homogeneity. A heterogeneous cloud will generally limit the placement of the downwind samplers to the portion of the cloud that contains the combined emissions from the various sources. It may also require the addition of samplers in the cloud to provide data on the extent of the effects of the heterogeneity and the consequent variability of the pollutant distributions. This parameter will not affect the upwind samplers.

Site Topography. Depending on the relationship of the topography obstructions and the wind direction, this parameter may affect both upwind and downwind samplers. Hills and valleys may cause lofting or depression of the pollutant cloud, requiring sampler elevation on towers or limiting the downwind distance of samplers within the cloud. They may also provide funnelling effects that limit the dispersion of the cloud and restrict the lateral positioning of the downwind samplers. Upwind sampler locations may be restricted by lofting or depression of the ambient air approaching the site.

Wind Direction. Changes in this parameter alone are not generally a major factor in the sampling system design. They will dictate

TABLE 3-2

MATRIX OF SAMPLING SYSTEM DESIGN PARAMETERS

Cloud Homogeneity	Site Topography	Wind Direction	Ambient Air Homogeneity
Homogeneous (1)	Open (1)	Not a Factor (0)	Homogeneous (1)
			Heterogeneous (2)
	Hill (2)	Parallel to Hill (1)	Homo (1)
			Hetero (2)
		Over Hill (2)	Homo (1)
			Hetero (2)
	Valley (3)	Down Valley (1)	Homo (1)
			Hetero (2)
		Across Valley (2)	Homo (1)
			Hetero (2)
Heterogeneous (2)	Open (1)	Not a Factor (0)	Homogeneous (1)
			Heterogeneous (2)
	Hill (2)	Parallel to Hill (1)	Homo (1)
			Hetero (2)
		Over Hill (2)	Homo (1)
			Hetero (2)
	Valley (3)	Down Valley (1)	Homo (1)
			Hetero (2)
		Across Valley (2)	Homo (1)
			Hetero (2)

Cloud Homogeneity:

- Homogeneous - Sources at site all emitting same pollutants. - Sources of different pollutants grouped so that emissions are mixed before sampling.
- Heterogeneous - Sources at site emitting identifiably different pollutants - no mixing before sampling.

Site Topography:

- Open - Site on flat terrain ambient air access from any direction unhindered.
- Hill - Site close enough to rise in terrain or large buildings to cause channeling or lofting of ambient air.
- Valley - Site between rises in terrain or large buildings.

Wind Direction:

- Parallel to Hill - Wind across site channeled against side of hill. Usually changes shape of pollutant cloud and distribution of pollutants within cloud.
- Across Hill - Wind across site from or to hill top. Can cause lofting of depression of pollutant cloud.
- Down Valley - Wind across site channeled against sides of hills.
- Across Valley - Wind across site from hill to hill.

Ambient Air Homogeneity:

- Homogeneous - Pollutants in approaching air evenly distributed.
- Heterogeneous - Pollutants in approaching air measurably different at points over site. Usually caused by emissions from nearby upwind external source.

changes in the design in combination with other factors such as site topography, described above, or the presence of external sources, which may influence the homogeneity of the approaching ambient air, described below.

Ambient Air Homogeneity. The presence of external emission sources that may result in variations in the pollutant concentrations and distributions in the air approaching a site may require the addition of samplers both upwind and downwind to ensure that the measurements of the pollutants of interest are not unduly influenced or masked. Samplers typically are required within and outside of the external source cloud both upwind and downwind.

Typical sampler locations for selected source site configurations illustrating some of these effects are sketched in Figure 3-1. The configurations are identified by a four-digit number referring, in left-to-right order, to the numbers assigned to the parameters identified in the matrix of Table 3-2. A configuration with a homogeneous cloud emitted at a valley site with cross-valley wind direction and homogeneous ambient air is thus identified as 1321.

3.4.3 Sampling Techniques

Sampling must be scheduled and carefully designed to ensure that data representative of the emission conditions of concern are obtained. Effective scheduling demands that sufficient knowledge of operations and process conditions be obtained to determine proper starting times and durations for samplings. The primary concern of the sampling design is that sufficient amounts of the various pollutants are collected to provide meaningful measurements.

Each of the various sample collection and analysis methods has an associated lower limit of detection, typically expressed in terms of micrograms of captured solid material and either micrograms or parts per million in air of gases. Samples taken must provide at least these

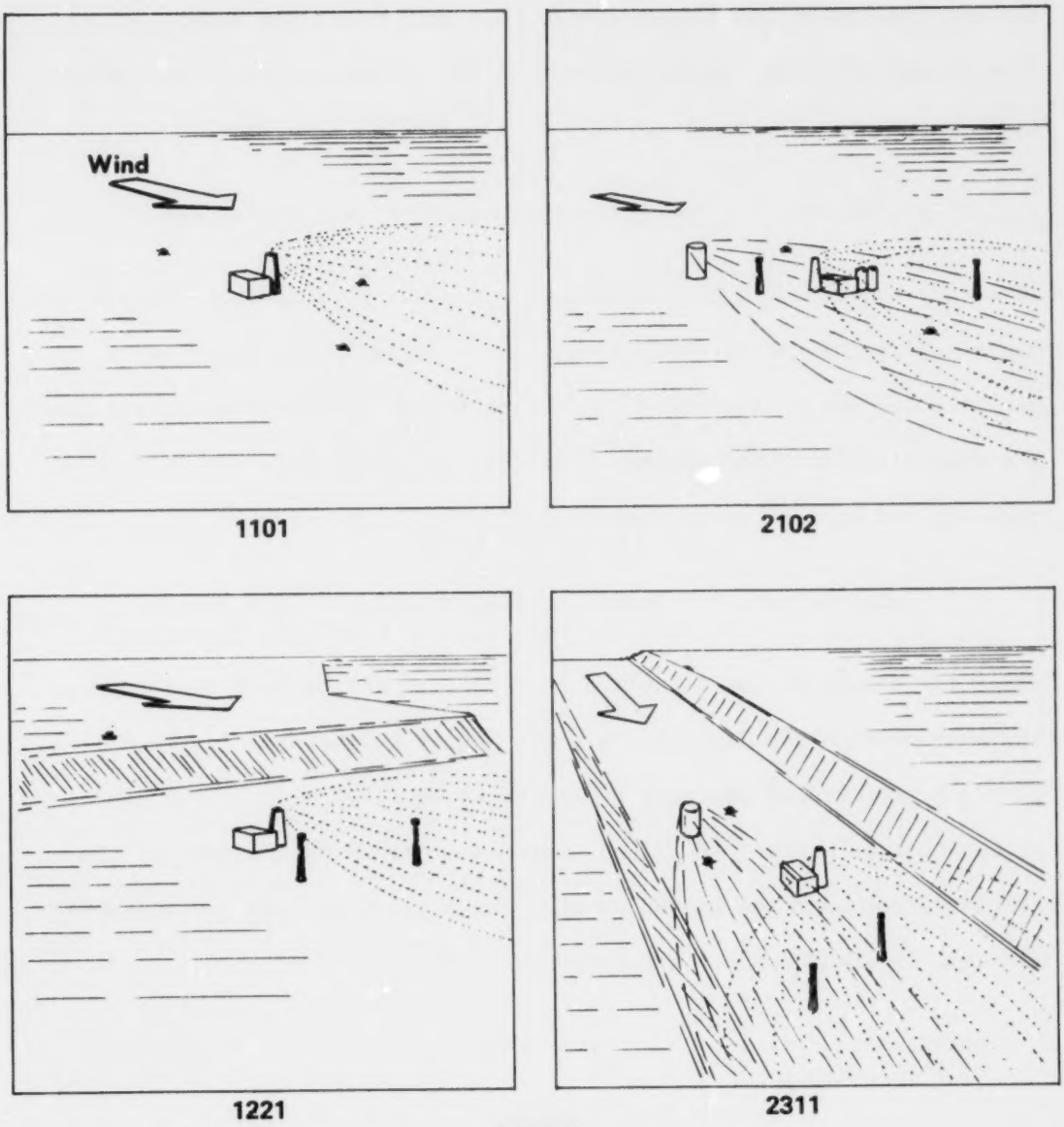

Fig. 3-1. Typical sampler locations for selected source site configurations.

minimum amounts of the pollutants to be quantified. The amount (M) of a pollutant collected is the product of the concentration of the pollutant in the air (χ) and the volume of air sampled (V), thus,

$$M \text{ (micrograms)} = \chi \text{ (micrograms/cubic meter)} \times V \text{ (cubic meters)}.$$

To ensure that a sufficient amount of pollutant is collected, an adequately large volume of air must be passed through such samplers as particle filters or gas absorbing trains for a specific but uncontrollable concentration. The volume of air (V) is the product of its flow rate (F) and the sampling time (T),

$$V \text{ (cubic meters)} = F \text{ (cubic meters/minute)} \times T \text{ (minutes)}.$$

Since the sampling time is most often dictated by the test conditions, the only control available to an experimenter is the sampling flow rate. A preliminary estimate of the required flow rate for any sampling location may be made if an estimate or rough measurement of the concentration expected is available. The subsitution and rearrangement of terms in the above equations yields Equation 3-1:

$$F \text{ (cubic meters/minute)} = M \text{ (micrograms)}/\chi \text{ (micrograms/cubic meter)} \times T \text{ (minutes)}. \quad (3\text{-}1)$$

This equation permits the calculation of the minimum acceptable flow rate for a required sample size. Flow rates should generally be adjusted upward by a factor of at least 1.5 to compensate for likely inaccuracies in estimates of concentration.

Grab-samples of gaseous pollutants provide for no means of pollutant sample quantity control except in terms of the volume of the sample.

Care should be taken, therefore, to correlate the sample size with the requirements of the selected analysis method.

Sampler location is also important in obtaining representative data. Downwind sampler location is especially critical to ensure that samples are taken at points known to be within the pollutant cloud at measurable concentrations. A rough estimate of acceptable downwind sampler locations may be made utilizing the basic equation[1] for the diffusion of gases and particulates in the atmosphere from a ground-level source: $\chi = Q/\pi Ku$, where

χ = pollutant concentrations at receptor point, gm/m^3
Q = source emission rate, gm/sec
K = product of standard deviations of vertical and horizontal pollutant distribution, m^2
u = wind speed, m/sec

This equation assumes a Gaussian distribution of pollutants in both the vertical and horizontal directions and no deposition or reaction of pollutants at the earth's surface.

By rearranging terms, the product of the standard deviations (K), which are functions of the downwind distance (x) of the receptor from the source, may be determined as a function of easily estimated or measured parameters in Equation 3-2:

$$K = Q/\pi\chi u, \qquad (3\text{-}2)$$

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[1] Turner, D. Bruce, "Workbook of Atmospheric Dispersion Estimates," U.S. Department of Health, Education and Welfare, Public Health Service Publication No. 999-AP-26, Revised 1969.

where

Q is estimated from published emission factors,
χ is set equal to a selected value related to the sampling method detection limit and
u is measured at the site.

The maximum downwind sampler distance from the source along the axis of the wind direction (x) may then be determined from the curves of Figure 3-2, which relate K and x for various atmospheric stability categories. These categories are listed and explained in Table 3-3.

When suitable x-distances, which may be any distance less than the maximum determined from Figure 3-2, have been selected, cross-wind distances (y) perpendicular to the x-axis that will ensure that samples are taken within the limits of the cloud must be determined. Maximum cross-wind distances, which are a function of the distribution of the pollutant concentrations within the cloud, are plotted as a function of x in the curves of Figure 3-3 for the same atmospheric stability categories used in determining x. Downwind samplers should in general be located at two different x-distances within the limits of the maximum as determined above and at cross-wind y distances less than the maximum indicated in Figure 3-3 on opposite sides of the wind direction axis.

Upwind samplers should ideally be located on the wind direction axis just far enough upwind to prevent sampling the backwash of the pollutant cloud. A minimum upwind distance of $x_{max}/10$, where x_{max} is determined using χ equal to the sampling method's lower detection limit, will usually be sufficient.

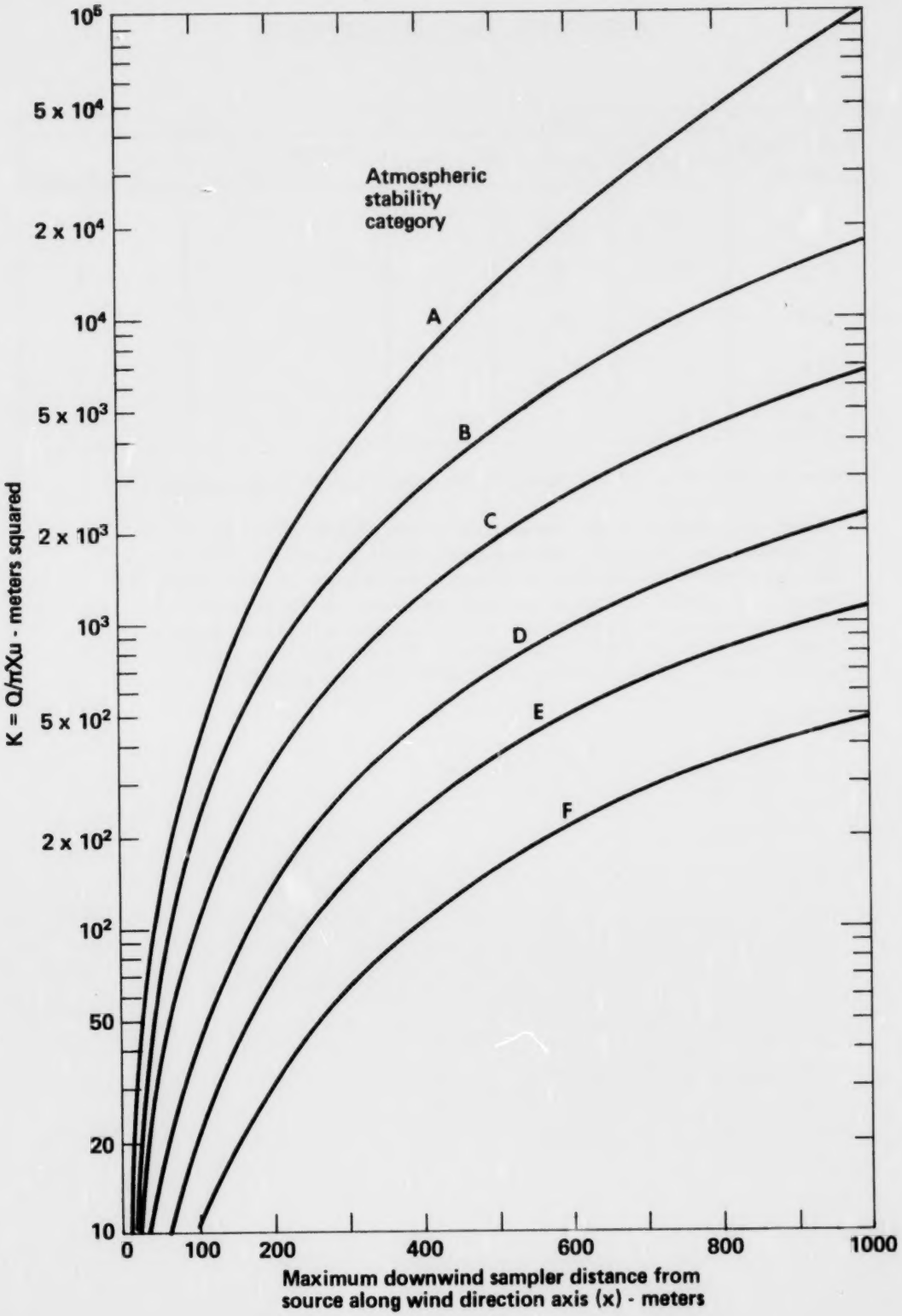

Fig. 3-2. Maximum downwind sampler distances.

TABLE 3-3

ATMOSPHERIC STABILITY CATEGORIES

Wind Speed m/sec	Day*			Night	
	Solar Altitude†			Overcast or > 50% Clouds	< 50% Clouds
	> 60°	35°-60°	15°-35°		
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

*Day is one hour after sunrise to one hour before sunset.

†Solar altitude may be determined form Table 170, Solar Altitude and Azimuth, Smithsonian Meteorological Tables. Use neutral class D for overcast conditions at any wind speed. - Parital cloud cover (60 percent to 85 percent) will reduce effective solar altitude one division (e.g., from > 60° to 35°-60°) for middle clouds and two divisions (e.g., from >60° to 15°-35°) for low clouds.

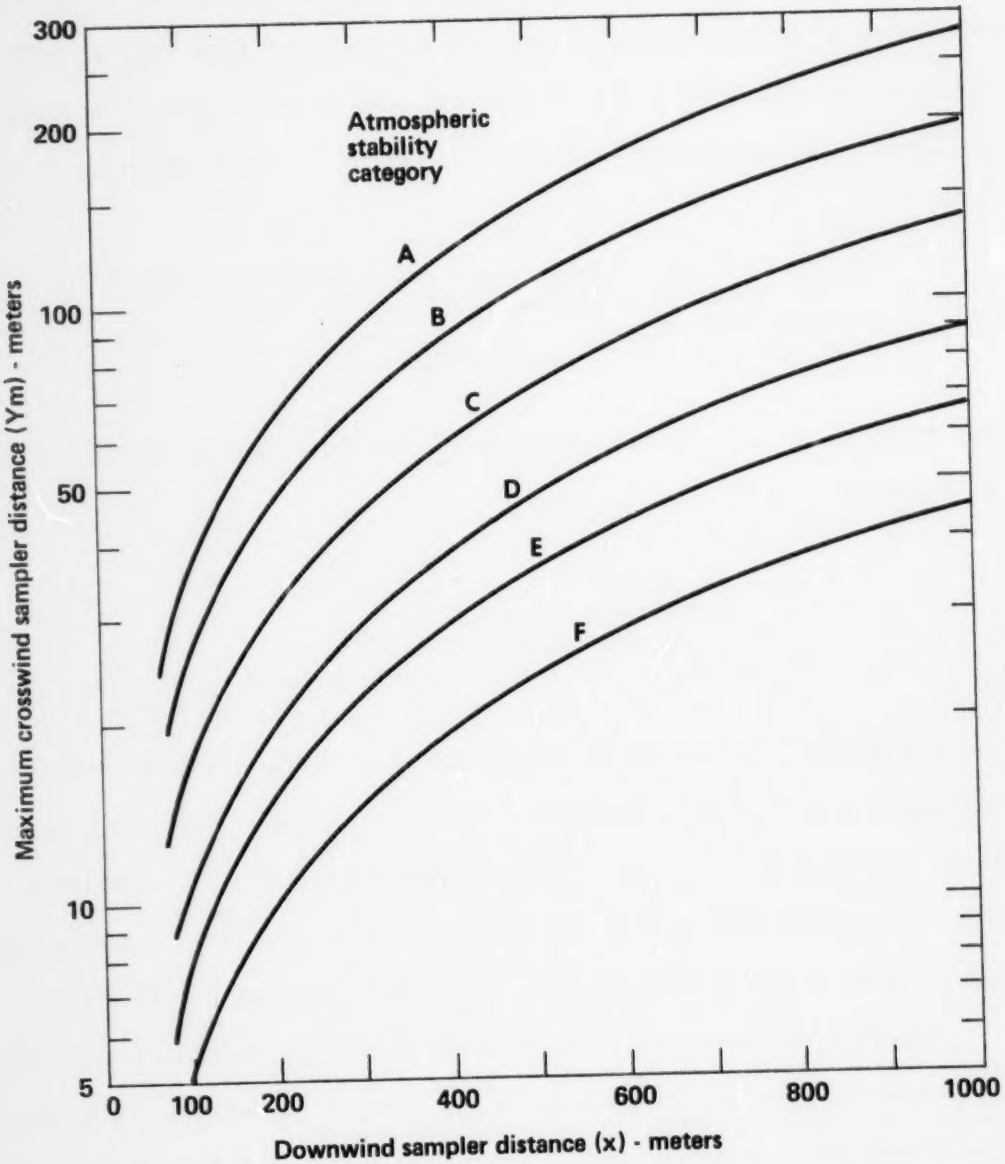

Fig. 3-3. Maximum crosswind sampler distances.

To illustrate the application of the equations and curves presented in this section, assume a source emitting particulates into a four meter per second wind at an estimated rate of 10 grams per second, and a sampler with a lower detection limit of .001 gram and flow rate of 0.67 cubic meter per minute. For a sampling time of 10 minutes, the required pollutant concentration, χ, at the sampler is $\chi = M/FT$, where

$M = .001$ gram
$F = 0.67$ cubic meter/minute x 1.5 adjustment factor = 1 cubic meter/minute
$T = 10$ minutes, and
$\chi = .001/10 = 10^{-4}$ grams/cubic meter

The product of the pollutant cloud's standard deviations, K, is found in Equation 3-2, $K = Q/\pi\chi u$, where

$Q = 10$ grams/second
$\chi = 10^{-4}$ grams/cubic meter
$u = 4$ meters/second, and
$K = 10/\pi \times 10^{-4} \times 4 = 8 \times 10^{3}$ meters squared

To measure the emissions during midday with clear skies, Table 3-3 indicates an atmospheric stability category B for the four meter/second wind. Figure 3-2 for $K = 8 \times 10^{3}$ and category B indicates a maximum sampler downwind distance of 680 meters. Figure 3-3 for x = 680 meters and category B indicates a maximum cross-wind distance of 145 meters.

Downwind samplers must then be located within the limits of a triangle with an apex at the source, an altitude of 680 meters along the wind direction axis and a base 145 meters wide on each side of the axis.

The upwind sampler should be located along the wind direction axis at a minimum distance of $x_{max}/10 = 68$ meters from the source.

A more detailed description of the application of this method is presented in the appendix.

3.4.4 Data Reduction

When the sampling program has been completed and the samples have been analyzed to yield pollutant concentrations in such terms as micrograms per cubic meter in the ambient air at each downwind sampling site, the measured upwind concentrations are subtracted to yield the concentration provided by the source at each sampler. These values are then back-calculated through known diffusion equations that take into account the variables of topography and meteorology to produce statistical distributions of the concentrations within a pollutant cloud generated by a given source. These calculations yield source strengths of the emissions in such terms as grams per unit time. A library of computer programs to assist in the performance of the calculations is maintained in the User's Network for Applied Models of Air Pollution (UNAMAP) at the Environmental Protection Agency's Research Triangle Computer Center.(1) Additional programs may be obtained through many environmental consultants.

3.5 Detailed Upwind-Downwind Measurement System

A detailed measurement system is designed to more precisely identify and quantify specific pollutants that a survey measurement or equivalent data indicate as a possible problem area. A detailed system

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(1) Bulletin American Meteorological Society, Vol. 56, No. 12, December, 1975.

is necessarily more complex than a survey system in terms of equipment, system design, sampling techniques, and data reduction. It requires a much larger investment in terms of equipment, time, and manpower and yields data detailed and dependable enough for direct action toward achieving emissions control. Detailed systems in general employ sampling arrays or networks to measure the concentration and distribution of specific pollutants in the ambient air approaching and leaving a source. These actual measurements of the pollutant distribution within a cloud and the variations in meteorological conditions during the sampling period replace the assumptions utilized in survey sampling systems. Detailed systems are frequently employed to compare emissions at different process or operating conditions to determine which conditions dictate the need for emission control.

The data provided by the sampling arrays are processed in conjunction with more detailed meteorological data which are taken simultaneously to determine source emission rates and ambient distributions in much the same manner as the simpler survey systems.

3.5.1 Sampling Equipment

The pollutants to be characterized by a detailed upwind-downwind sampling system fall into the same two basic classes--airborne particulates and gases--as those measured by survey systems. Detailed sampling and analysis equipment is generally selected to obtain continuous or semi-continuous measurements of specific pollutants rather than simple grab-sampled measurements.

Particulate samples are collected using filter impaction, piezo-

electric, particle change transfer, light or radiation scattering, electrostatic, and size selective or adhesive impaction techniques. Gases are sampled and analyzed using flame ionization detectors, bubbler/impinger trains, non-dispersive infrared or ultraviolet monitors, flame photometry, and other techniques specific to individual gaseous pollutants.

The selection of suitable sampling equipment should be influenced by such considerations as portability, power requirements, detection limits and ease of control.

3.5.2 Sampling System Design

The basic criteria reviewed in Section 3.4.2 for the design of a survey sampling system are generally applicable to the design of a detailed system. The need for replacement of survey assumptions as to pollutant distribution with actual measured values, however, most frequently requires the design of a sampling array or network that will provide samples of a distribution at various distances downwind of the source in both the horizontal and vertical directions. Sampler locations may generally be determined in the same manner as those for a survey system. For detailed measurements, each location must provide for sampling across a section of the pollutant cloud horizontally and/or vertically. Horizontal distributions may be measured by adding a number of samplers (usually at least two) at either side of the survey sampler location at distances estimated to yield significantly different pollutant concentrations. Vertical distributions may be measured by placing a tower of suitable height at each survey sampler location

and adding samplers over a range of heights on each tower. Combinations of horizontal and vertical distributions may be measured by placing a grid of horizontally and vertically spaced samplers at each survey sampler location. Actual numbers of samplers, their spacing, and heights of towers required must be determined for each location. A rough guide for estimating the required spacing is presented in Section 3.5.3.

3.5.3. Sampling Techniques

The guidelines presented in Section 3.4.3 for the design and location of samplers for a survey system are applicable to detailed systems. The assumption of a Gaussian distribution of pollutants in the cloud, sufficient for data reduction in survey systems is reasonable as a rough guide to locating samplers within the pollutant cloud as in Section 3.4.3, and for the spacing of sampling arrays as outlined below.

The approximate concentration of a specific pollutant within a cloud in which concentrations vary in accordance with a Gaussian distribution at a given downwind distance from the source is greatest at ground level on the wind direction axis of the cloud. Assigning this concentration the unit value χ_0, the concentration (χ) at any crosswind distance (y) from the axis is expressed as

$$\chi = \chi_0 \, e^{-\frac{1}{2}[F(y)]^2}$$

The term F(y) may be expressed as y/y_m, where y_m is the maximum crosswind sampler distance determined from Figure 3-3. The relationship χ/χ_0 is plotted as a function of y/y_m in Figure 3-4. This may be used to

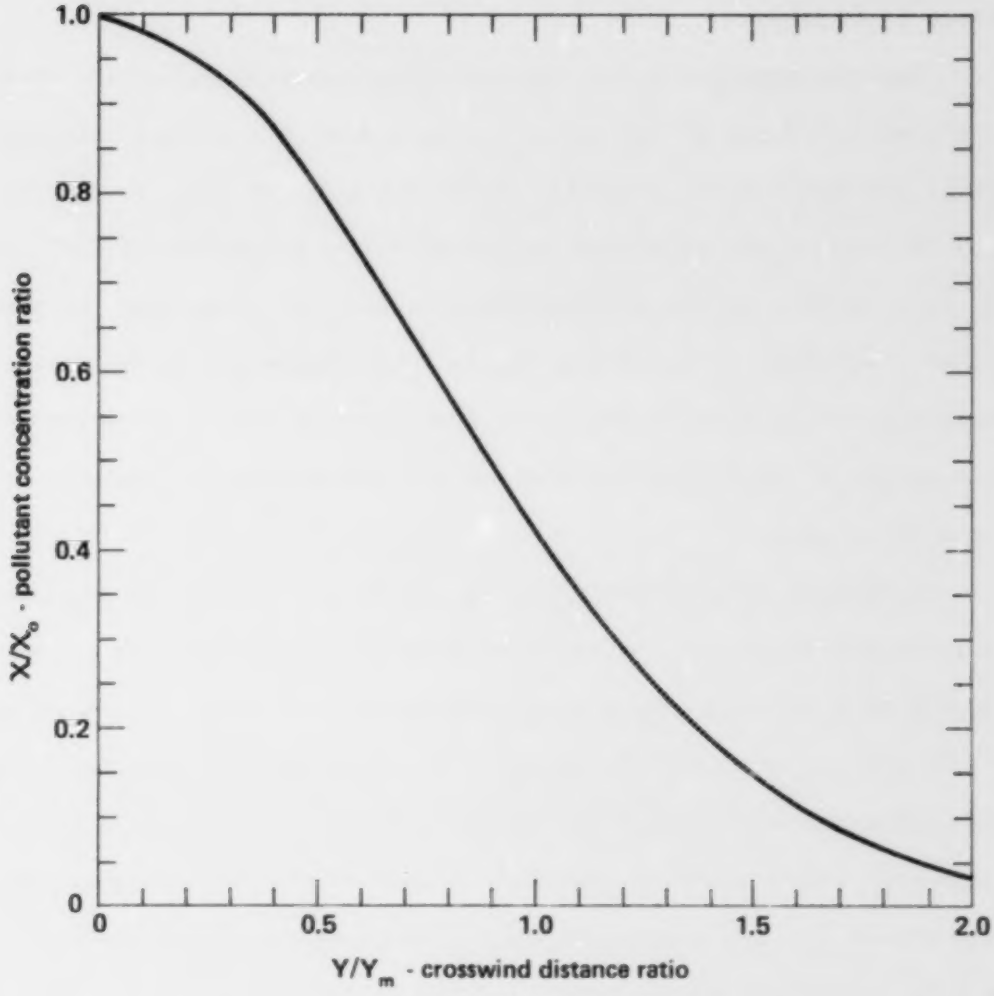

Fig. 3-4. Pollutant concentration ratios for crosswind locations.

determine the probable concentration at a sampler location relative to the concentration at the axis and the concentrations at lateral distances from that location to assist in the horizontal spacing of samplers in an array.

The concentration in the vertical direction from any ground level point will decrease as the height, Z, increases in a similar relationship. The ratio of the concentration at the elevated point to that at ground level, χ_h/χ, is plotted in Figure 3-5 as a function of Z/Z_m, where Z_m is a function of the downwind distance from the source and the atmospheric stability as plotted in Figure 3-6. Figure 3-5 may be used to determine the relative concentrations at elevated points to assist in the design of sampling towers and the vertical spacing of samplers in an array or grid.

In general, arrays should be designed to provide data at concentrations approximately two to four times greater or less than the concentration at a selected ground level sampling point. Physical limitations at the site or very unstable atmospheric conditions will often preclude the compliance with this design guideline by limiting the available horizontal positions or by requiring an impractical tower height. In such situations, the need to adjust the requirements of the guideline must be recognized and the array designed to compensate for the limitations.

Upwind sampling arrays will generally be less complex than downwind arrays unless a nearby pollutant source results in a heterogeneous ambient air mix. In this case, the guidelines for downwind array design presented in this section may have to be applied to the upwind array

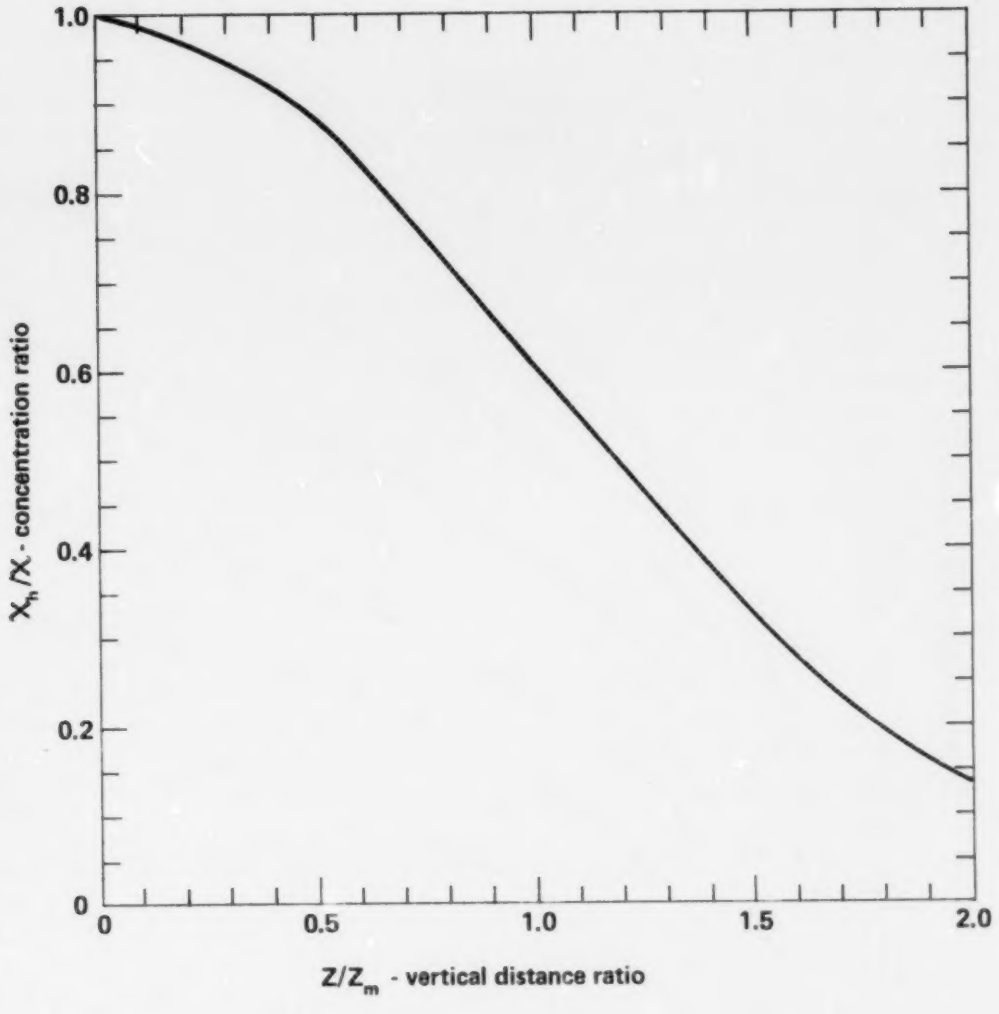

Fig. 3-5. Pollutant concentration ratios for vertical locations.

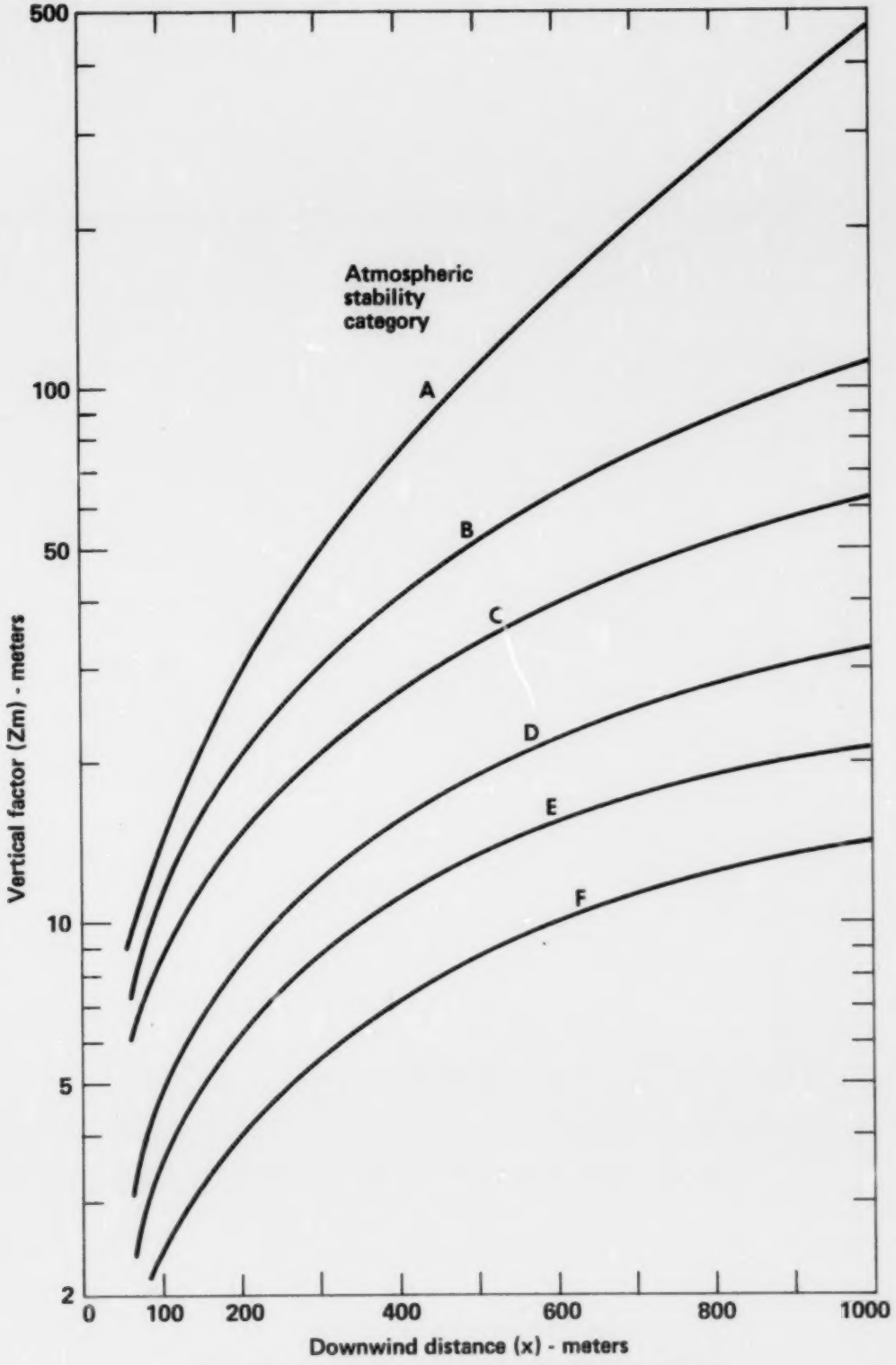

Fig. 3-6. Vertical concentration distribution factors.

design.

Wind speed and direction should be measured at each sampler or array location. Pretest survey observations should indicate whether stratification will occur to a degree which will require wind data at more than one level.

An example of the application of these guidelines to the design of survey and detailed systems for the measurement of pollutants at a Portland cement plant is presented as an appendix to this document.

3.5.4. Data Reduction

Samples are analyzed to yield concentrations of specific pollutants in such terms as micrograms per cubic meter at each sampling site. Measured upwind concentrations are substituted into appropriate diffusion equations to provide ambient air background concentrations at each downwind site and the background concentration subtracted from the measured downwind concentration at each site to yield the source contribution. These values are then substituted into diffusion equations to back-calculate source strengths in terms of grams per unit time, utilizing UNAMAP or other available computer programs.

3.6 Atmospheric Tracers

In some instances, prevailing process or meteorological conditions prohibit the collection of samples containing measurable, clearly defined amounts of a specific pollutant for the back-calculation of source strengths. In many such cases, the atmospheric tracer method may be employed to determine a typical distribution of a general class of pollu-

tant analogous to the pollutant of concern.

The use of tracers should be considered under any of the following circumstances:

When the pollutant background concentration is either excessively high or inhomogeneous. This can be caused by significant emissions from external upwind sources.

When the fugitive emissions are of such a complex nature that an excessive number of downwind vertical profiles are required to characterize the emissions.

When physical limitations prohibit the installation of adequate instrumentation for specific pollutant concentration measurement.

When the nature of the specific pollutant prohibits its measurement with acceptable instrumentation or indicates large probable errors in measurement.

When estimates of fugitive emissions are being made for non-operating processes or planned operations.

The atmospheric tracer method, which may be considered as a special detailed system, consists of the introduction into the atmosphere, at the source site under consideration, of a readily identifiable material similar in the character of its diffusion in the atmosphere to the pollutant of concern. The quantity released may be controlled to provide readily measurable concentrations. A detailed downwind measurement system, designed using the guidelines of Section 3.5, is used to collect samples of the tracer and to determine its dispersion for the known and controllable source strength. This dispersion will be analogous to the dispersion of the pollutant of concern and will permit the prediction of pollutant concentrations for a range of source strengths.

3.6.1 Tracers and Samplers

Both particulate and gaseous atmospheric tracers are in general use. The most commonly used particulate tracers are zinc-cadmium sulfide and sodium fluorescein (urinine dye). The primary gaseous tracer is sulfur hexafluoride (SF_6).

Zinc-cadmium sulfide is a particulate material which can be obtained in narrow size ranges to closely match the size of the pollutant of concern. The material is best introduced into the atmosphere in dry form by a blower type disseminator although it can also be accomplished by spraying from an aqueous or solvent slurry. The zinc-cadmium sulfide fluoresces a distinctive color under ultraviolet light which provides a specific and rapid means of identification and quantification of the tracer in the samples.

Sodium fluorescein is a soluble fluorescing particulate material. It is normally spray disseminated from an aqueous slurry solution to produce a particulate airborne plume, the size distribution of which can be predetermined by the spraying apparatus. Sodium fluorescein can be uniquely identified by colorimeter assessment.

Sulfur hexafluoride is a gas which can be readily obtained in ordinary gas cylinders. Sulfur hexafluoride can be disseminated by metering directly from the gas cylinder through a flow meter to the atmosphere. The amount disseminated can be determined by careful flow metering and/or weight differentiation of the gas cylinder.

Particulate tracers are usually sampled with filter impaction devices or, for particles over 10 microns in diameter, the more easily used and somewhat less accurate Rotorod sampler which collects particles

on an adhesive-coated U- or H-shaped rod which is rotated in the ambient air by a battery-driven electric motor.

Sulfur hexafluoride gaseous samples are collected for laboratory gas chromatograph analysis in non-reactive bags of such materials as Mylar.

3.6.2 Tracer Sampling System Design

All of the design guidelines presented in 3.4.2 and 3.5.2 may be applied to the design of a tracer sampling system as site conditions dictate. Their application is, in general, simplified since the source strength may be controlled to provide measurable tracer concentrations at readily accessible sampling locations.

A single upwind sampler will usually be sufficient to establish that no significant amount of the tracer material is present in the ambient atmosphere approaching the source.

3.6.3 Tracer Sampling and Data Analysis

The methods introduced in Section 3.4.3 and 3.5.3 for determining sampler design and location are fully applicable to tracer sampling. Like the design guidelines, they may be more easily applied because the source strength is easily controlled.

The analysis of the data is also simplified since the source strength is known and no back-calculation is required.

3.7 Quality Assurance

The basic reason for quality assurance on a measurement program is to insure that the validity of the data collected can be verified. This requires that a quality assurance program be an integral part of the measurement program from beginning to end. This section outlines the quality assurance requirements of a sampling program in terms of several basic criteria points. The criteria are listed below with a brief explanation of the requirements in each area. Not all of the criteria will be applicable in all fugitive emission measurement cases.

1. Introduction

   Describe the project organization, giving details of the lines of management and quality assurance responsibility.

2. Quality Assurance Program

   Describe the objective and scope of the quality assurance program.

3. Design Control

   Document design requirements and standards applicable to the measurement program as procedures and specifications.

4. Procurement Document Control

   Verify that all design specification accompany procurement documents such as purchase orders.

5. Instructions, Procedures, Drawings

   Prescribe all activities that affect the quality of the work performed by written procedures. These procedures must include acceptance criteria for determining that these activities are accomplished.

6. Document Control

   Ensure that the writing, issuance, and revision of procedures which prescribe measurement program activities affecting quality are documented and that these procedures are distrib-

uted to and used at the location where the measurement program is carried out.

7. Control of Purchase Material, Equipment, and Services

Establish procedures to ensure that purchased material conforms to the procurement specifications and provide verification of conformance.

8. Identification and Control of Materials, Parts, and Components

Uniquely identify all materials, parts, and components that significantly contribute to program quality for traceability and to prevent the use of incorrect or defective materials, parts, or components.

9. Control of Special Processes

Ensure that special processes are controlled and accomplished by qualified personnel using qualified procedures.

10. Inspection

Perform periodic inspections where necessary on activities affecting the quality of work. These inspections must be organized and conducted to assure detailed acceptability of program components.

11. Test Control

Specify all testing required to demonstrate that applicable systems and components perform satisfactorily. Specify that the testing be done and documented according to written procedures, by qualified personnel, with adequate test equipment according to acceptance criteria.

12. Control of Measuring and Test Equipment

Ensure that all testing equipment is controlled to avoid unauthorized use and that test equipment is calibrated and adjusted at stated frequencies. An inventory of all test equipment must be maintained and each piece of test equipment labeled with the date of calibration and date of next calibration.

13. Handling, Storage, and Shipping

Ensure that equipment and material receiving, handling, storage, and shipping follow manufacturer's recommendations to prevent damage and deterioration. Verification and documentation that established procedures are followed is required.

14. Inspection, Test, and Operating Status

Label all equipment subject to required inspections and tests so that the status of inspection and test is readily apparent. Maintain an inventory of such inspections and operating status.

15. Non-Conforming Parts and Materials

Establish a system that will prevent the inadvertent use of equipment or materials that do not conform to requirements.

16. Corrective Action

Establish a system to ensure that conditions adversely affecting the quality of program operations are identified, corrected, and commented on; and that preventive actions are taken to preclude recurrence.

17. Quality Assurance Records

Maintain program records necessary to provide proof of accomplishment of quality affecting activities of the measurement program. Records include operating logs, test and inspection results, and personnel qualifications.

18. Audits

Conduct audits to evaluate the effectiveness of the measurement program and quality assurance program to assure that performance criteria are being met.

4.0 ESTIMATED COSTS AND TIME REQUIREMENTS

Table 4-1 presents a listing of the conditions assumed for estimating the costs and time requirements of upwind-downwind fugitive emissions sampling programs using the methodology described in this document. Four programs are listed, representing minimum and more typical levels of effort for each of the survey and detailed programs defined in Section 3.3. The combinations of conditions for each program are generally representative of ideal and more realistic cases for each level and will seldom be encountered in actual practice. They do, however, illustrate the range of effort and costs that may be expected in the application of the upwind-downwind technique except in very special instances.

4.1 Manpower

Table 4-2 presents estimates of manpower requirements for each of the sampling programs listed in Table 4-1. Man-hours for each of the three general levels of Senior Engineer/Scientist, Engineer/Scientist, and Junior Engineer/Scientist are estimated for the general task areas outlined in this document and for additional separable tasks. Clerical man-hours are estimated as a total for each program. Total man-hour requirements and approximately 500 man-hours for a simple survey program and 1500 man-hours for a more complex survey program; and 2800 man-hours for a simple detailed program and 4500 man-hours for a more complex detailed program.

TABLE 4-1

CONDITIONS ASSUMED FOR COST ESTIMATION
OF UPWIND - DOWNWIND SAMPLING PROGRAMS

Parameter	Survey Program		Detailed Program	
	Simple	Complex	Simple	Complex
Site Location	Open Area-Accessible	Congested-Limited Access	Open Area-Accessible	Congested-Limited Access
Emmission Source	Well Defined	Complex	Well Defined	Complex
Emission Character	Steady	Steady	Cyclic	Cyclic-Measured at Two Levels
Wind Measurement	External Source	Measured On Site	Measured On Site	Two Measurements On Site
Sample Sites	One Upwind Two Downwind	One Upwind Three Downwind	Vertical Arrays-One Upwind, Two Downwind	Grid Arrays-One Upwind, Two Downwind
Samplers	3	8	16	30
Towers	0	4 Low	4 High	4 High - Grids
Experiments	1	1	2	4
Estimated Basic Accuracy	± 500%	± 150%	± 125%	± 75%

TABLE 4-2

ESTIMATED MANPOWER REQUIREMENTS FOR UPWIND - DOWNWIND SAMPLING PROGRAMS

Estimates in Man-Hours

Task	Survey Programs						Detailed Programs					
	Simple			Complex			Simple			Complex		
	Senior Engr/Sci	Engr/ Sci	Junior Engr/ Tech	Senior Engr/Sci	Engr/ Sci	Junior Engr/ Tech	Senior Engr/Sci	Engr/ Sci	Junior Engr/ Tech	Senior Engr/Sci	Engr/ Sci	Junior Engr/ Tech
Pretest Survey	4	12	0	8	24	0	8	24	0	12	36	16
Test Plan Preparation	8	12	0	12	16	4	12	24	12	16	32	12
Equipment Acquisition	4	4	12	4	8	28	8	24	48	12	36	52
Field Set-Up	8	12	12	16	48	64	80	140	100	120	280	240
Field Study	24	48	120	60	200	268	120	300	536	180	560	796
Sample Analysis	20	20	36	60	60	108	120	240	96	180	320	180
Data Analysis	20	20	36	60	60	108	120	240	96	180	320	180
Report Preparation	16	16	8	64	64	32	160	80	40	200	200	80
Totals	104	144	224	284	480	612	628	972	1028	900	1784	1556
Engineer/Scientist Total		472			1376			2628			4240	
Clerical		40			120			200			280	
Grand Total		512			1496			2828			4520	

4.2 Other Direct Costs

Table 4-3 presents estimates for equipment purchases, rentals, calibration, and repairs; on-site construction of towers and platforms; shipping and on-site communications for each of the listed programs. Total costs are approximately $4500 for a simple survey program and $17,000 for a more complex survey program; and $34,000 for a simple detailed program and $64,000 for a more complex detailed program.

4.3 Elapsed-Time Requirements

Figure 4-1 presents elapsed-time estimates for each of the listed programs broken down into the task areas indicated in the manpower estimates of Table 4-2. Total program durations are approximately 12 weeks for a simple survey program and 17 weeks for a more complex survey program; and 21 weeks for a simple detailed program and 41 weeks for a more complex detailed program.

4.4 Cost Effectiveness

Figure 4-2 presents curves of the estimated cost effectiveness of the upwind-downwind technique, drawn through points calculated for the four listed programs. Costs for each program were calculated at $30 per labor hour, $40 per man day subsistence for field work for the manpower estimates of Table 4-2, plus the other direct costs estimated in Table 4-3.

TABLE 4-3

ESTIMATED COSTS FOR UPWIND - DOWNWIND
SAMPLING PROGRAMS
(LABOR COSTS EXCLUDED)

	Survey Programs		Detailed Programs	
Cost Item	Simple	Complex	Simple	Complex
Equipment				
Sampler Purchase	$1800	$4800	$9600	$18000
Sequencer Purchase	900	2400	4800	9000
Wind Measurement Purchase	0	3500	3500	5000
Calibration	150	250	400	600
Repairs	270	1000	1500	2500
Wiring Harnesses	0	0	400	800
Construction				
Towers	0	2000	8000	19000
Platforms, etc.	500	1000	1500	2000
Electrical Hook-ups	0	100	200	300
Shipping	200	400	800	1200
Trailer Rental	0	0	500	500
Vehicle Rentals	280	560	1400	2800
On-Site Communications	100	300	700	900
TOTAL	$4500	$16810	$34100	$63900

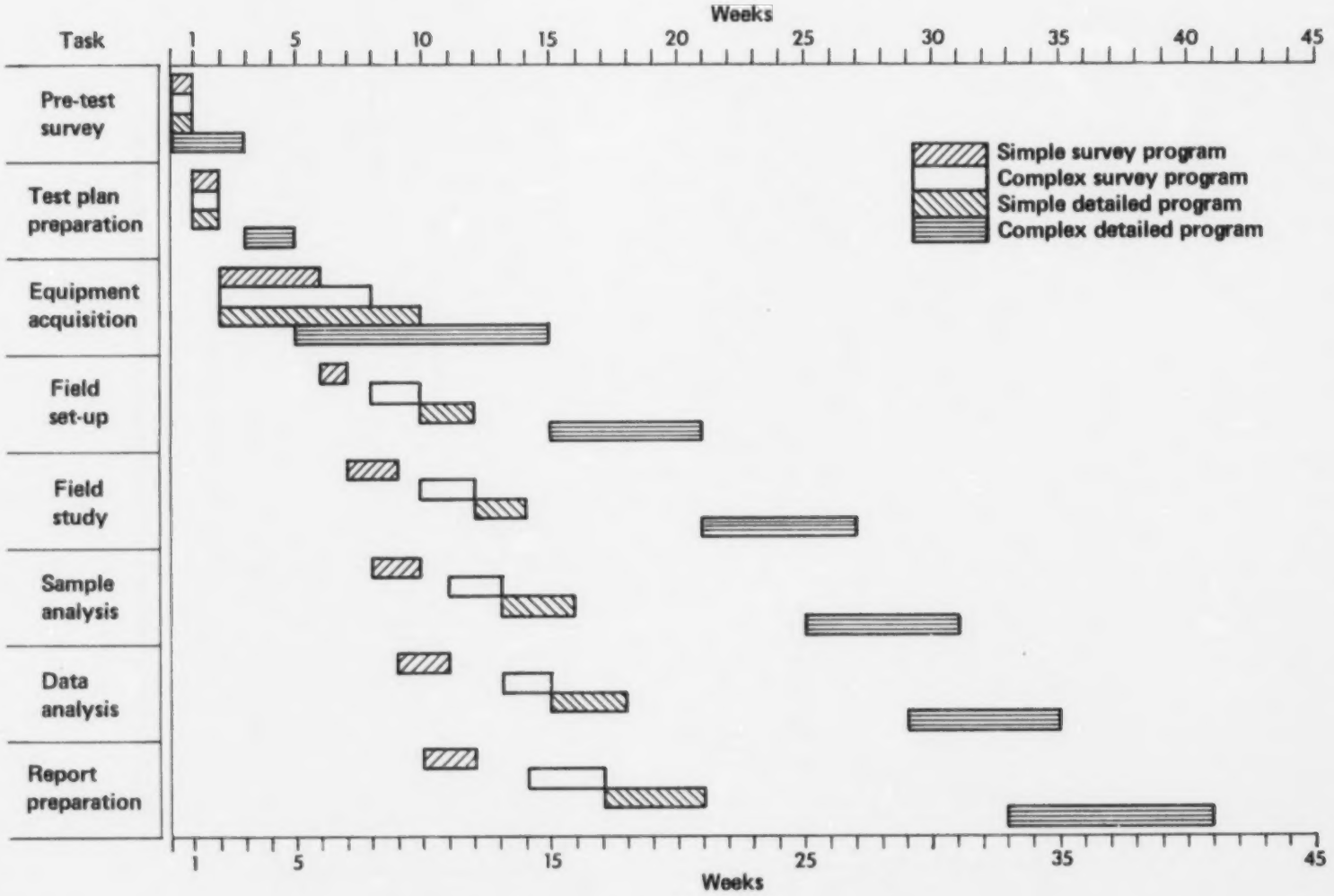

Fig. 4-1. Elapsed-time estimates for upwind-downwind sampling programs.

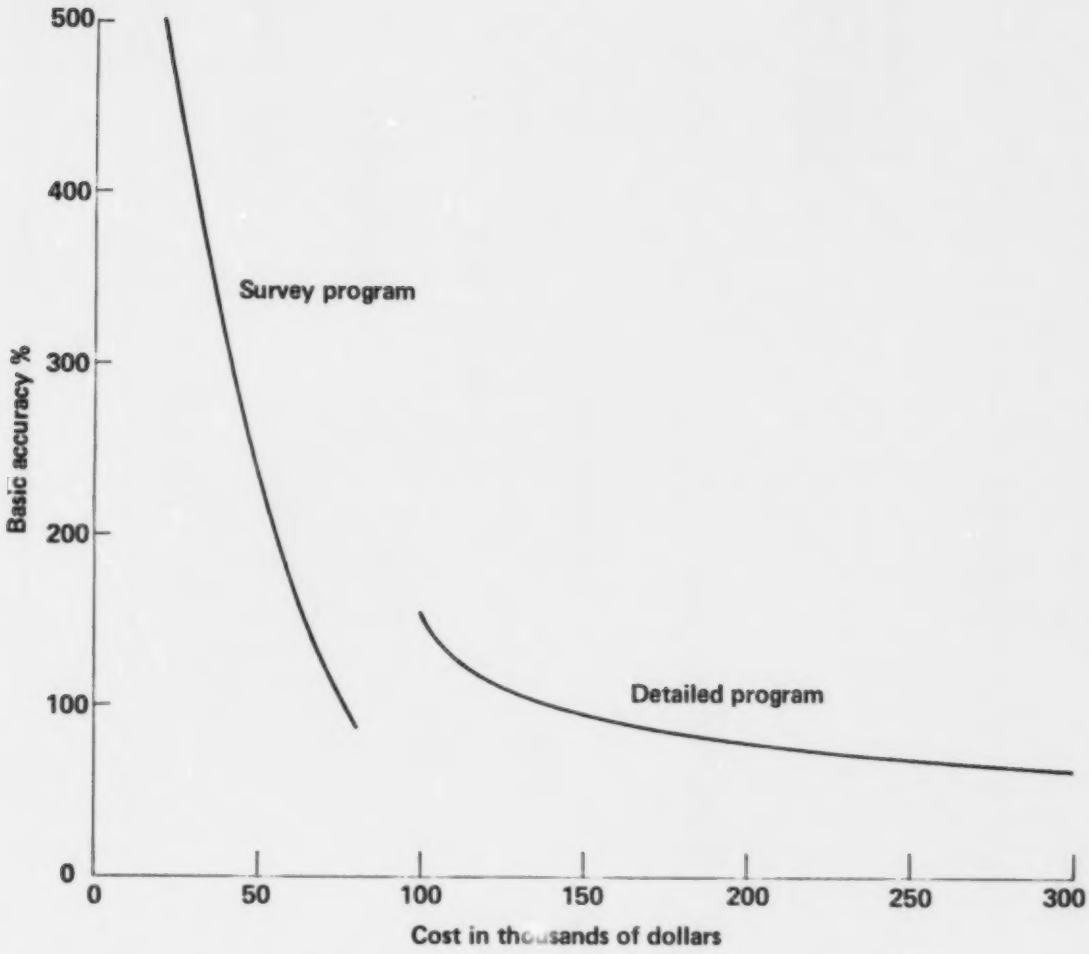

Fig. 4-2. Cost-effectiveness of upwind-downwind sampling programs.

APPENDIX A

TEST PROCEDURES APPLICATION

A.1.0 INTRODUCTION

This appendix presents an application of the upwind-downwind fugitive emissions measurement system selection and design criteria to a Portland cement manufacturing plant. The criteria for the selection of the method and the design procedures for both survey and detailed sampling systems as presented in Sections 3.4 and 3.5 of this document are discussed.

A.2.0 BACKGROUND INFORMATION

The following information relative to the operation of the subject Portland cement manufacturing plant would ordinarily be gathered from interviews and observations during a visit to the plant for a pretest survey.

Portland cement is made from a mixture of finely ground calcareous (lime component) and argillaceous (alumina component) materials. The four major steps for producing Portland cement are:

(1) Obtaining raw materials and reducing their size,

(2) Grinding, blending and homogenization of these materials to obtain desired composition and uniformity,

(3) Heating to liberate carbon dioxide and burning to form clinker,

(4) Grinding or fine pulverization of the clinker with addition of gypsum.

At this location, shown in Figure A-1, limestone is quarried at the site by dragline buckets, pulverized in a hammer mill, mixed with water and pumped to raw material storage. Other raw materials are delivered to storage by rail. Ball mills reduce first the limestone and then a limestone-clay mixture to a fine slurry which is stored in concrete tanks prior to its introduction to the rotary kilns. The slurry is dried and burned at about 2700°F to form clinker, which is cooled and stored in bins until needed for the finish grinding operation where it is pulverized and mixed with gypsum to produce the finished product. The cement is stored in silos prior to bagging or transfer to bulk container trucks and railroad cars for shipping.

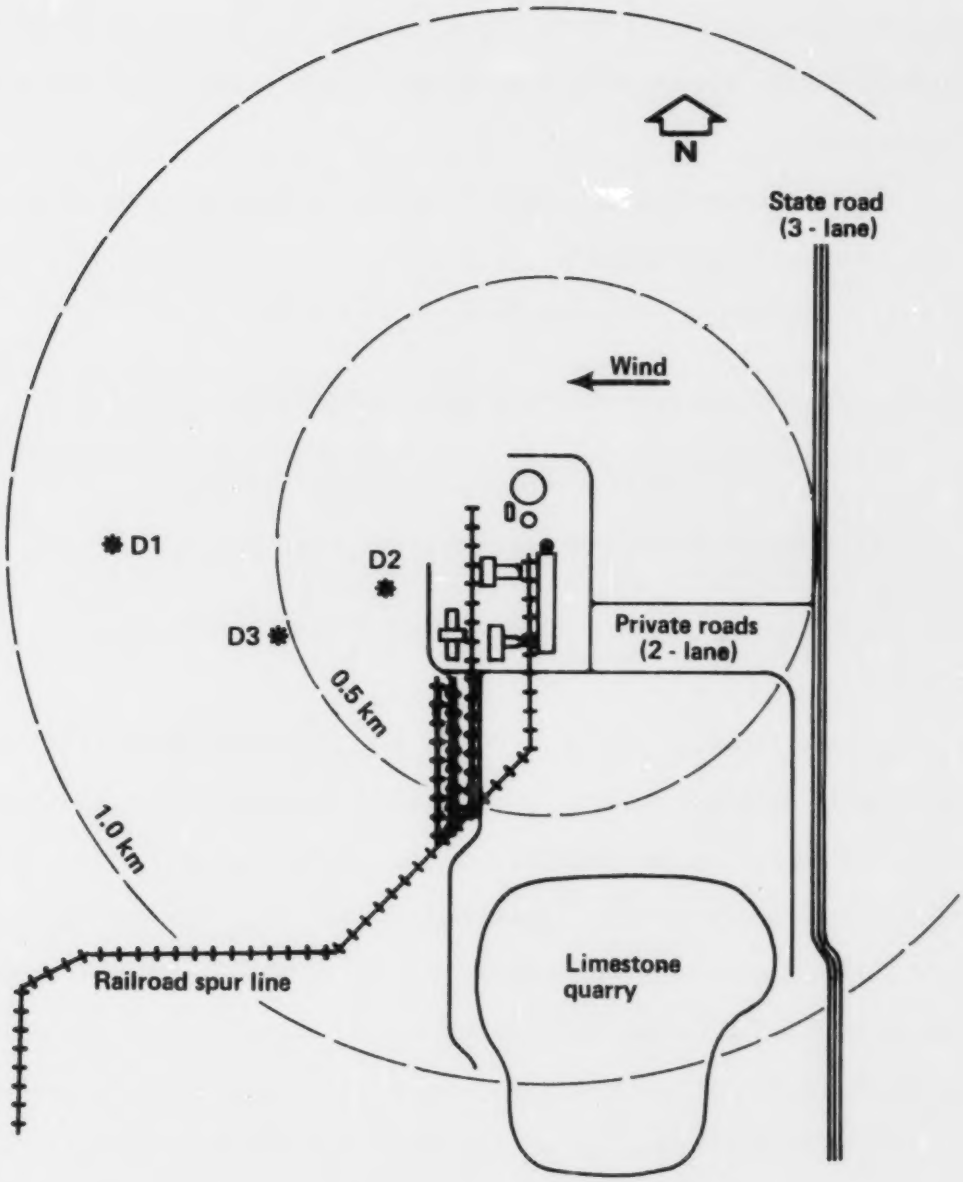

Fig. A-1. Portland cement plant site layout.

The plant operates on a three-shift, round-the-clock production schedule including all operations except shipping and unloading of rail-delivered raw materials, which are normally carried out only on the 8:00 a.m. to 4:00 p.m. shift. The plant produces about 300 barrels of finished product per hour, consuming about 600 pounds of raw materials for each 376 pound barrel produced.

The raw materials and the finished product are essentially dust; the principal emissions are also dust. The largest contributor is the kiln used to produce the clinker, where the dried mixture becomes suspended in the combustion gases as dust and is delivered through the stack to the atmosphere. A multi-cyclone/electrostatic precipitator combination removes about 95 percent of the dust before it is vented to the stack. Other sources of dust are the ball mills, materials transfer operations and packaging operations. Hoods at the ball mills and packing house are utilized to capture and transmit about 85 percent of their emissions to a bag house. The quarry operation at this plant contributes little or no dust since the entire process is conducted with the material in a wet condition.

The EPA estimates for uncontrolled emissions, as published in the Office of Air Programs Publication AP-42, Compilation of Air Pollutant Factors, are 15 to 55 pounds from the kiln and 2 to 10 pounds from all other sources for each barrel of cement produced. If the assumed 95 percent effectiveness of the stack controls is correct, 0.75 to 2.75 pounds per barrel could be transmitted to the atmosphere from the stack. Assuming that 80 percent of all other emissions are hooded, 0.5 to three pounds per barrel could be transmitted to the atmosphere as fugitive

emissions.

The prevailing daytime wind at the plant is from a general easterly direction and averages 10 miles per hour over open, flat, partly swampy terrain.

A.3.0 METHOD SELECTION

Selecting the most practical method to measure the amount of emitted pollutants reaching the ambient atmosphere involves evaluating the site, processes and pollutants concerned in terms of the criteria of Section 2.2 as follows:

> Site Criteria - the various sources at the site are remote from one another, both indoors and outdoors, and are not small enough to be hooded or otherwise enclosed.
>
> Process Criteria - emissions are essentially the same from all sources at the site with no interfering reactions between emissions or with other constituents in the ambient atmosphere. The process is continuous and does not entail any limitations as to the timing of sampling.
>
> Pollutant Criteria - emissions to be measured are particulates whose generation rate and dilution in the ambient air will provide measurable concentrations within reasonable distances of the source.

The site criteria are, in this case, the determining factors in selecting the measurement method. Since the emissions cannot be contained or directed in any manner, only the upwind-downwind measurement method may be successfully utilized to determine the plant's contribution to the particulate concentration in the local atmosphere.

The basic question to be answered by the measurement program is "Does the rate of particulate emissions from the plant exceed the accepted regulatory agency standard?" This question can be answered by a survey program average measurement of the total particulate emissions from the plant, including emissions from the kiln stack. If the survey program indicates that the plant's emissions do exceed standards, the question to be answered will then be "What actions are neces-

sary to reduce emissions to an acceptable rate?" The answer to this question requires that the rates of the specific sources of the emissions be separately quantified. This will require the increased accuracy and extent of measurements of a detailed program. The design of both systems is described in the following sections.

A.4.0 SURVEY MEASUREMENT SYSTEM

To determine the total plant contribution of particulates to the atmosphere, measurement must be made of the approaching ambient air containing upwind and all background emissions. In this case, a single upwind sampler located between the kiln building and the road to the east will include the general ambient background particulates plus the particulates contributed by traffic on the road. A ground level sampler, located about 200 meters from the kiln, should provide an accurate measurement. The downwind measurement must include the contributions from all the sources at the site, which may be considered as emanating from a line source at ground level with an overlay of emission from the elevated stack, as illustrated in Figure A-2. To ensure that the stack emission contribution to the cloud is being measured, one downwind sampler is located within the estimated confines of the stack plume and others outside the stack plume as shown on Figure A-2.

A.4.1 Sampler Location

For a high volume sampler sampling 18 cubic feet per minute, a desired sample weight of 100 micrograms and a 60 minute sampling time, the particle concentration required at the sampling point is: (per Equation 3-1)

$$\chi = M/FT = 10^{-4} \text{ (gm)}/0.5 \text{ (m}^3\text{/min)} \times 60 \text{ (min)}$$

$$\chi = 3.3 \times 10^{-6} \text{ (gm/m}^3\text{)}$$

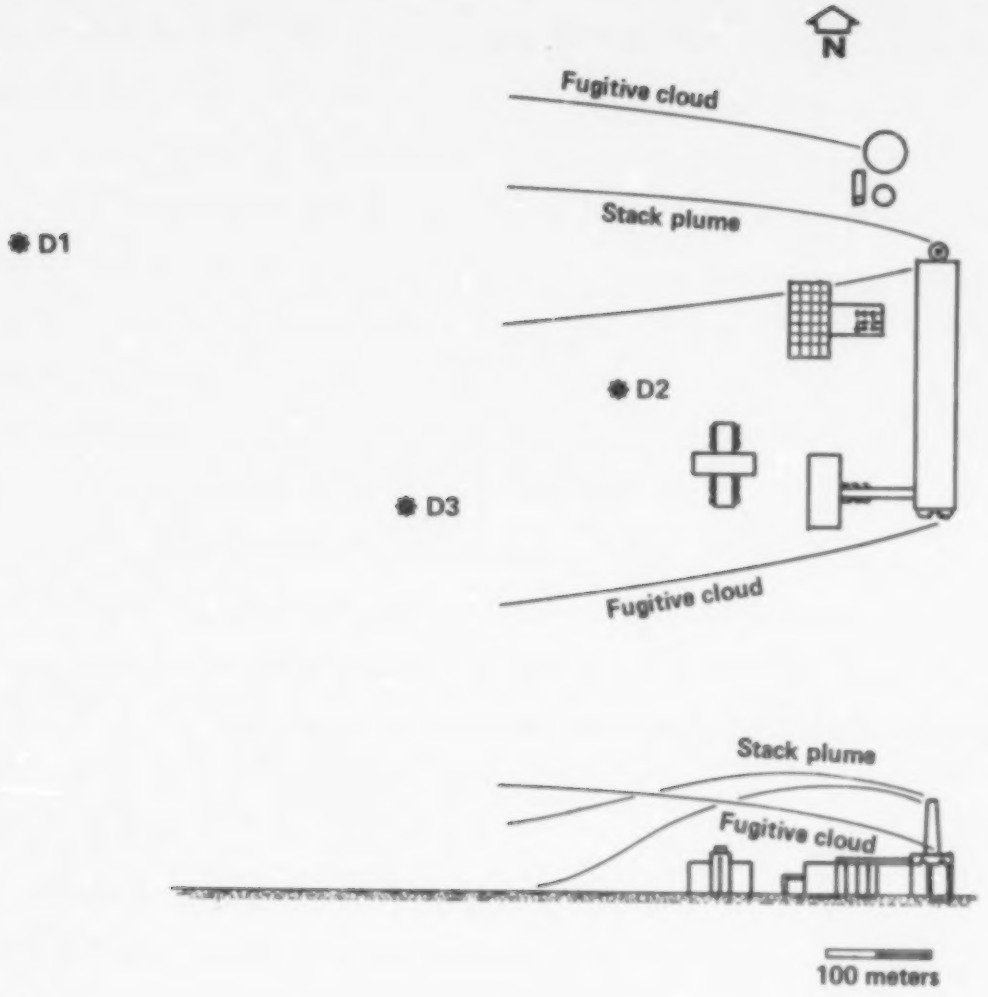

Fig. A-2. Portland cement plant emissions clouds.

Local emission limitations, promulgated on a process weight basis, permit 30 pounds per hour of particulate to be transmitted to the atmosphere from all sources. In order to measure this total emission rate in a 10 mile per hour (4.47 m/sec) wind with the proposed samplers, the product of the standard deviations used to determine the maximum distance from the source that samplers may be located is found using:

$$K = Q/\pi\chi u \qquad \text{(Equation 3-2)}$$

$$K = 30 \times 454 \times \frac{1}{3600} \left(\frac{gm}{sec}\right)/\pi \times 3.3 \times 10^{-6} \left(\frac{gm}{m^3}\right) \times 4.47 \left(\frac{m}{sec}\right) = 8 \times 10^4$$

Table 3-3 indicates the use of an atmospheric stability category B for clear midday conditions and the wind speed of 4.47 meters per second. Figure 3-2 indicates a maximum sampler downwind distance well in excess of one kilometer for $K = 8 \times 10^4$ and category B, so that any sampler location within one kilometer downwind of the plant will provide satisfactory measurements. To ensure that the stack emissions are also adequately measured, one sampler is located along the wind direction axis through the stack at a distance of 800 meters from the stack, at point D1 on Figure A-2. Two additional samplers are located within the fugitive emissions cloud outside the stack plume at points D2, 300 meters from the kiln structure on its wind direction centerline, and D3, 500 meters from the kiln at 100 meters to the south (cross-wind) of its centerline.

Samples are taken simultaneously at the upwind and three downwind locations for a one hour period chosen to include activities in all phases of the process- kiln operation, grinding, packaging and all phases

of material transfer including bulk product loading and raw material unloading. The samples are analyzed to determine particulate concentrations at the sampler locations, which are then used in computer programmed diffusion equations to determine the source strengths of the fugitive and stack emissions.

A.5.0 DETAILED MEASUREMENT SYSTEM

Assuming that the survey measurements indicate an emission rate in excess of the local regulations, say 40 pounds per hour, a detailed system must be designed to more accurately quantify the emissions from the separate sources at the plant.

The separate sources are identified as individual particulate clouds on Figure A-3. Their characteristics and schedules are as follows:

(1) Flotation Tanks - continuous low level emissions. Cloud usually isolated.

(2) Ball Mill and Slurry Tanks - continuous emissions. Cloud usually mixed with (3).

(3) Raw Materials Storage - continuous low level emissions, higher emissions during day shift material unloading operations. Cloud always mixed with (2).

(4) Packing and Shipping - emission level variable with activity on day shift only. Cloud always partially mixed with (5).

(5) Finish Grinding Mill - continuous emissions. Cloud partially mixed with (4).

(6) Stack - continuous emissions.

(7) Materials Transfer - continuous low level emissions as background to all except (1).

Assuming that the prevailing wind direction remains from the east:

Cloud (1) may be individually measured at any time.

Cloud (2) may be individually measured only when material unloading operations are shut down - measurement would be improved by wetting down raw materials.

Cloud (3) may not be individually measured. Emissions may be quantified by measuring total of clouds (2) and (3) and subtracting individual measurement of (2).

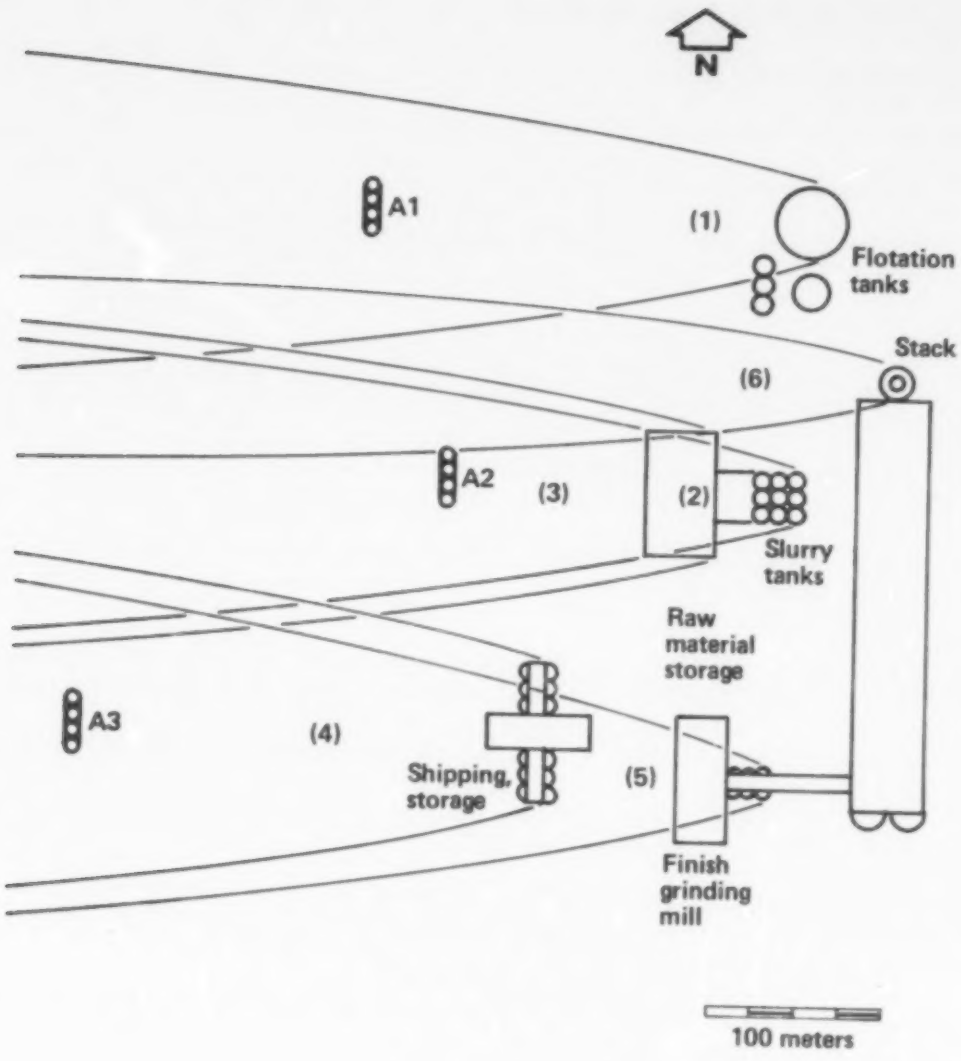

Fig. A-3. Portland cement plant separate source clouds.

Cloud (4) may not be individually measured. Emissions may be quantified by measuring total of clouds (4) and (5) and subtracting individual measurement of (2).

Cloud (5) may be individually measured when packing and shipping operations are shut down.

Cloud (6) emissions may be measured by stack sampling at any time.

Cloud (7) emissions may not be individually measured. Their low level background contribution is present in all clouds measured except (1).

To measure the source strengths associated with clouds (1) through (5), a network of individual arrays may be set up as follows:

Array [1] - in cloud (1)

Array [2] - in combined clouds (2) and (3)

Array [3] - in combined clouds (5) and (6)

Samples taken during first shift operations using all three arrays will provide measurments of the particulate concentrations in cloud (1), the combined concentrations of clouds (2) and (3) and the combined concentrations of clouds (4) and (5). Samples should be taken during materials unloading operations to provide measurements of the maximum concentrations of cloud (3) and during maximum activity level in the shipping area to provide measurements of the maximum concentrations of cloud (4).

Samples taken during second or third shift operations using arrays [2] and [3] will provide measurements of the particulate concentrations of clouds (2) and (5).

Stack samples may be taken at any convenient time.

Analyses of the samples will provide particulate concentrations at

the array locations for each source, which may then be back-calculated to provide equivalent source strengths, which, with appropriate subtractions described above, will give individual source strengths.

The flotation tanks are located very nearly at ground level and may reasonably be considered a ground level source. Array [1] may therefore be composed of only ground level samplers located across the cloud (1) generated by these tanks.

Raw material storage generates a ground level source cloud (3), while the ball mills and the slurry tanks generate an elevated cloud (2). The array [2] used to sample these clouds must then employ both ground level and elevated samplers located across the portion of the cloud combining the emissions of both sources.

Packing and shipping operations generate a cloud (4) of both ground level and elevated emissions, as do the finish grinding mill and clinker storage in cloud (5). Array [3] must then be composed of ground level and elevated samplers located across the portion of the cloud combining the emissions of both clouds.

Assumptions as to the approximate source strengths for each of the sources are made to provide the starting points for determining array locations and spacing. Based on the 40 pound per hour rate for the total emissions indicated by the survey measurements, a source strength of eight pounds per hour is assigned to each of the sources of clouds (2) through (5), and four pounds per hour for the sources of clouds (1) and (7). The conditions of the survey example of Section A.4.1; with a 10 mile per hour wind from the east, an atmospheric stability category B, a desired sample weight of 100 micrograms and a 60 minute sampling

time are assumed to apply to the detailed system.

The best locations for the arrays, each within the clouds they are designed to measure and away from the influences of other clouds, are shown at A1, A2 and A3 on Figure A-3.

For array [1], located about 250 meters downwind of the source of cloud (1) in order to avoid the influence of neighboring clouds, the approximate particle concentration on the wind direction axis at ground level is determined from Equation 3-2, rearranged as

$$\chi = Q/\pi Ku, \text{ where}$$

χ = concentration (gm/m^3)
Q = source strength = 4 (lbs/hr) = 0.5 (gm/sec)
K = 110 (m^2) - from Figure 3-7
u = 4.47 (m/sec), and

$$\chi = 3.2 \times 10^{-5} (gm/m^3)$$

The required sampler flow rate is determined from Equation 3-1, rearranged as

$$F = M/\chi T, \text{ where}$$

F = flow rate (m^3/min)
M = sample weight = 10^{-4} (gm)
χ = 3.2×10^{-5} (gm/m^3)
T = sampling time = 60 (min), and

$$F = 5.2 \times 10^{-2} \ (m^3/min)$$

The cross-wind spacing of the samplers in the array is determined by assigning a particle concentration desired to be measured at a sampler location of about 1/2 the concentration at the wind direc-

tion axis, or, $\chi = 1.6 \times 10^5$ (gm/m^3), and calculating its ratio to the calculated concentration on the wind direction axis, χ_0. In this case, $\chi/\chi_0 = 0.5$. Figure 3-4 indicates a value of 0.91 for the cross-wind distance ratio y/y_m, in which y is the desired cross-wind sampler distance and y_m is the maximum cross-wind distance determined from Figure 3-3. In this case, y_m for x = 250 meters and category B is 68 meters, and y = 62 meters.

Array [1], then, would consist of three ground level samplers located 250 meters downwind of the flotation tanks with the central sampler on the wind axis and two samplers 62 meters away, one in each of the two cross-wind directions. This array will provide measurement of at least two particle concentrations within the cloud for use in the back calculation of the source strength at the flotation tanks.

Similar computations may be made for each of the other arrays, with the addition of a vertical spacing determination using Figures 3-5 and 3-6 in the same manner as Figures 3-3 and 3-4 for the determination of cross-wind spacing.